

IN THE ABSTRACT

Please accept the substitute Abstract enclosed as Attachment III.

REMARKS

The purpose of the amendment is to correct the above cited application so that it is in condition for allowance.

The Office Action requested a correction to the Abstract. This has been done.

All references to Figure 9 have been eliminated by this Amendment as it is not necessary.

In accordance with Section 714.01 of the M.P.E.P., the following information is presented in the event that a call may be deemed desirable by the Examiner to: William G. Auton, (781) 377-3773.

Respectfully submitted,



WILLIAM G. AUTON
Attorney for Applicants

ATTACHMENT 1

Figure 5. Band diagram (Γ - Γ) of biased, strain-balanced type-I 5-layer photodetector

Figure 6. Band diagram (Γ - Γ) of biased, unbalanced type-II 4-layer photodetector

Figure 7. Band diagram (Γ - Γ) of biased, unbalanced type-I 4-layer photodetector

Figure 8. Photodetector for the $1.55 \mu\text{m}$ wavelength. This detector employs the Fig. 5 heterostructure.

DETAILED DESCRIPTED OF PREFERRED EMBODIMENTS

We describe interband embodiments first, then intersubband devices. We have identified three strained-layer direct-gap structures that are useful for band-to-band photodetection as well as lasing, emission, amplification, and modulation in the near-infrared and middle-infrared regions: (A) strain-compensated Type I MQW of tensile-strained Ge barriers, compressively-strained $\text{Ge}_{1-2x}\text{Sn}_{2x}$ quantum wells, grown upon a relaxed buffer of $\text{Ge}_{1-x}\text{Sn}_x$ upon silicon, wherein electrons and holes are confined in $\text{Ge}_{1-2x}\text{Sn}_{2x}$; (B) an unsymmetrically strained Type-II system of tensile Ge and unstrained $\text{Ge}_{1-x}\text{Sn}_x$ grown on relaxed $\text{Ge}_{1-x}\text{Sn}_x$ upon silicon, with holes confined in Ge and electrons in $\text{Ge}_{1-x}\text{Sn}_x$; (C) an unsymmetrically strained Type-I system with tensile Ge wells, compressive $\text{Ge}_{1-x}\text{Sn}_x$ barriers, grown upon relaxed $\text{Si}_y\text{Sn}_x\text{Ge}_{1-x-y}$ upon silicon, with electrons and holes in Ge. Figures 1, 2, and 3 show the results of our first-principles band-offset calculations.

Attachment 2

Turning now to the preferred embodiments of the intersubband devices, there are three key structures; the quantum cascade laser, the quantum staircase laser, and the quantum well infrared photodetector (QWIP). The strain-balanced MQW heterosystem A, with Type I alignment and band diagram similar to Fig. 5, is preferred for all three device categories. The offset diagram of Fig. 1 indicates that the GeSn QWs will be generally shallow, hence the intersubband devices of this invention are optimum for longwave IR or far IR operation. Again, all devices are tunable by design via the choice of QW alloy composition and layer thicknesses. The laser resonators, the waveguided structures and mesa structures are similar to those in the intersubband device literature and are not shown here.

The intersubband lasers (not illustrated here) use either conduction subbands such as CB3, CB2, CB1 or valence subbands such as HH2, LH1 and HH1. These PIP or NIN GeSn/Ge cascade lasers use electrical injection of carriers and resonant tunneling of carriers between adjacent periods of the MQW. By contrast, the GeSn/Ge quantum well infrared photodetectors (QWIPs) do not employ resonant tunneling, and the QWs rather than being undoped, are doped N-type in an NIN sensor, or P-type in a PIP QWIP. The PIP device allows normal incidence sensing. The NIN uses end-fire input or grating assisted normal incidence sensing.

When Figs. 1-3 are used for GeSn/Ge device design, parabolic conduction bands are obtained and this is novel for Group IV devices. By contrast, for example, in the SiGe system, the conduction bands have many valleys in k-space. In the intersubband case, the MQW stack thickness can be several microns as desired for